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PERFORMANCE OF A WET SCRUBBER TO REDUCE LONG-LIVED RADIOACTIVE DUST EMISSIONS IN UNDERGROUND URANIUM MINES

J. BIGU, M.G. GRENIER AND S. HARDCASTLE

ELLIOT LAKE LABORATORY

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PERFORMANCE OF A WET SCRUBBER TO REDUCE LONG-LIVED RADIOACTIVE DUST EMISSIONS IN UNDERGROUND URANIUM MINES

by

J. Bigu*, M.G. Grenier** and S.G. Hardcastle**

ABSTRACT

The performance of a wet scrubber to control long-lived and short-lived radionuclides, associated with airborne particulate matter in the submicron and respirable ranges, has been investigated. The study was conducted during hard rock crushing operations at a crusher plant in an underground uranium mine. Measurements were carried out of long-lived radioactive dust concentration and radon progeny and thoron progeny Working Levels. Furthermore, mineral dust and radioactive dust size distributions were also measured by means of 8-stage cascade impactors. Measurements were preferentially conducted at the crusher platform, the wet scrubber itself, and in an area adjacent to the crusher. Experimental data show that the wet scrubber was very efficient in reducing the long-lived concentration of long-lived radioactive dust and in removing radioactive particulate matter of size greater than about 2 μm. A modest reduction in radon progeny and thoron progeny concentration was also noticed during the operation of the wet scrubber. It is concluded that the dust collector (scrubber) tested represents a very efficient means of controlling long-lived radioactive dust emissions from underground uranium mine operations.

Key words: Wet scrubber; Uranium mines; Radioactive dust; Emissions.

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**Research Scientist, Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada.

RENDEMENT D'UN ÉPURATEUR À VOIE HUMIDE UTILISÉ POUR RÉDUIRE LES ÉMISSIONS DE POUSSIÈRE RADIOACTIVES DANS LES MINES D'URANIUM SOUTERRAINES

par

J. Bigu*, M. Grenier** et S. Hardcastle**

RÉSUMÉ

Nous avons étudié le rendement d'un épurateur à voie humide utilisé pour le contrôle des radionucléides de longue et de courte période associés aux substances aéroportées des particules inhalables et de celles dont la dimension est inférieure à un micron. L'étude a été menée pendant les travaux de concassage de roche dure, à une installation de concassage, dans une mine d'uranium souterraine. Nous avons mesuré les concentrations de poussière radioactive de longue période et le niveau d'activité des descendants du radon et du thoron. De plus, les dimensions granulométriques de la poussière minérale et de la poussière radioactive ont également été mesurées au moyen d'impacteurs à cascades à huit étages. Les mesures ont été effectuées de préférence sur la plateforme ou se trouvaient le concasseur et l'épurateur, à proximité du concasseur. Les données expérimentales indiquent que l'épurateur à voie humide est très efficace pour réduire la concentration de longue durée de poussière radioactive de longue durée et enlever les substances radioactives des particules d'une taille supérieure à environ 2 um. Nous avons également pu observer une légère diminution de la concentration de descendants du radon et du thoron pendant que l'épurateur à voie humide était en marche. Les données indiquent que le capteur de poussière (l'épurateur) soumis à l'essai est très efficace pour le contrôle des concentrations de poussière radioactive dans les mines d'uranium souterraines.

Mots-clé : épurateur à voie humide; mines d'uranium; poussière radioactive; émissions.

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**Chercheur scientifique, Laboratoire d'Elliot Lake, CANMET, Énergie, Mines et Ressources Canada.

INTRODUCTION

Significant amounts of dust in the respirable range (1 to ~10 μm), and of size greater than 10 μm, are generated in the course of mining operations and various other mining activities.

Dust emissions from underground uranium mines contain radionuclides from the natural radioactive decay chains of uranium (^{235}U and ^{238}U) and thorium (^{232}Th).

A number of radionuclides have been identified by α-spectrometry, γ-spectrometry, neutron activation analysis and other methods, in dust clouds from underground uranium mines. The radionuclides identified include the parents of the natural decay chains as well as several of their long-lived and short-lived decay products.

Inhalation of dust poses a health hazard. Inhalation of radioactive dust poses an even greater potential occupational health problem. Because of this, methods aimed at controlling and reducing dust emissions are of paramount importance from the health viewpoint.

A number of methods and techniques have been developed to reduce airborne dust emissions. These include: mechanical filtration, wetting (e.g., water sprays), scrubbing and electrostatic precipitation, among other methods.

This paper presents a study on the effect of a wet scrubber as a means of reducing the short-lived and long-lived radioactivity associated with aerosol and dust generated during a rock crushing operation in underground hard rock uranium mines.

EXPERIMENTAL SITE

The study was conducted in a crushing plant at an underground (hard

rock) uranium mine. The crusher was fed by two ore passes and one waste pass. There was an open flow of muck where these three passes joined to feed the screen and the crusher. These fed a surge bin which was drawn by an operator at the tail pulley of a belt conveyor in a drift approximately 15 m below. On average, the plant crushed about 1.4×10^3 kg of ore or waste during the sampling periods.

The wet scrubber was an 8.7 $m^3 s^{-1}$ (air unit). Dusty air was fed to the dust collector via an intake plenum and ducts, from four dust producing areas, namely:

a) below the crusher screen and jaws;

b) the crusher pit;

c) a hood extracting dusty air from the open ore pass junction above the crusher platform; and

d) a hood at the tail pulley transfer point.

The wet scrubber operated on a continuous basis and was flushed daily at the beginning of the working shift. The crusher plant was ventilated with air (9.4 $m^3 s^{-1}$) coming from working sites of an upper level. The wet scrubber replaced a 7.1 $m^3 s^{-1}$ (air) bag collector which drew air from underneath the crusher jaws, and from the tail pulley transfer point dust collection hood, it then exhausted into an adjacent ore pass. The bag collector was replaced because of numerous mechanical and engineering problems.

EXPERIMENTAL PROCEDURE

The performance of the wet scrubber for air quality control purposes was evaluated during a period of several weeks. Experimental data were collected before and after the installation and operation of the wet scrubber. The study consisted of evaluating the radioactive dust collection efficiency

of the wet dust collector and assessing its impact on air quality in the crusher plant.

Measurements were preferentially conducted at the wet scrubber itself, the crusher platform, i.e., crusher operator work station, and the crusher plant floor, i.e., mechanic's work bench. In addition, measurements were also carried out at the air intake of the crusher plant, the ore passes feeding the crusher, and the return air path going to the tail pulley area.

A number of radioactivity measurements were made. These included:

a) the short-lived (thoron progeny) and long-lived α-particle radioactivity associated with dust samples;

b) the airborne radon progeny and thoron progeny concentration levels from air samples. Radon progeny activity concentration and radon progeny Working Levels, WL(Rn), and thoron progeny Working Levels, WL(Tn), were measured.

The short-lived and long-lived radioactivity associated with dust were measured from samples collected by means of cascade impactors, nylon cyclones and CAMPEDS (gravimetric dust samplers (1)).

Radon progeny and thoron progeny Working Levels were measured using grab-sampling methods (2,3). Measurements of WL(Rn) and WL(Tn) were made preferentially at the mechanic's work bench.

Short-lived and long-lived radioactive dust concentration and size distribution were measured using 10-stage cascade impactors Model 210 manufactured by Sierra Instruments U.S.A., now Andersen (U.S.A.). The impactors were operated with 8 stages, instead of 10 stages, at a nominal air flow-rate of 13 L min^{-1}. The last two ultrafine impactor stages were removed at the expense of losing some size distribution information but with the benefit of substantially increasing the amount of dust collected on the remaining 8 impactor stages.

The procedures followed to determine dust concentration and size distribution from cascade impactor data have been amply documented elsewhere (4,5) and will not be discussed here. However, some definitiions often encountered in this paper are given below.

The Equivalent Aerodynamic Diameter (EAD) is defined as the size of a spherical particle of density 1 g cm^{-3} which has the same terminal settling velocity as the sampled particle. The variable $D_{P,50}$ is defined as the particle size cut-off at 50% collection efficiency for spherical particles. Mass Median Aerodynamic Diameter, Activity Median Aerodynamic Diameter and geometric standard deviation are abbreviated, respectively, MMAD, AMAD, and σ_g. The MMAD and AMAD indicate, respectively, the median of dust mass distribution or the median of the radioactivity distribution associated with the dust, with respect to aerodynamic diameter.

EXPERIMENTAL RESULTS AND DISCUSSION

Experimental data have been summarized in Tables 2 to 5 and Figures 1 to 7. Table 1 shows the cut-off size of the different cascade impactor stages at the nominal operating sampling rate of about 13 L min^{-1}. Two identical cascade impactors were used at the same operating conditions and hence, same cut-off sizes.

Table 2 shows Long-Lived Radioactive Dust (LLRD) concentration, [LLRD], data for two different locations at the crusher plant, i.e., crusher platform and mechanic's work bench, before and after the operation of the wet scrubber. Also shown in the table is [LLRD] measured at the intake and exhaust of the scrubber. Measurements in this case were conducted through special sampling ports designed for the purpose as described elsewhere (6).

The data of Table 2 show a large difference in [LLRD] between the crusher platform and the mechanic's work bench before the wet scrubber went

into operation. This difference is attributed to the fact that the mechanic's work bench is located in the relatively fresh air intake path, and hence, not so severely affected by crushing operations. Although the difference in [LLRD] between the crusher platform and mechanic's work bench during the operation of the wet scrubber was less accentuated than when the scrubber was not operating, the difference was, nevertheless, very substantial. This suggests that the dust collector had also quite a significant effect on the work bench area.

Table 2 also shows that the wet scrubber reduced the long-lived radioactive dust concentration, [LLRD], by about 68% at the crusher platform, and by approximately 39% at the mechanic's work bench location. The [LLRD] reduction at the crusher itself was slightly over 87%.

Table 3 and Figures 1 to 5 summarize MMAD and AMAD data for dust, long-lived dust, and thoron progeny before and during operation of the wet scrubber. (The Figures show the percentage cumulative α-particle activity or dust mass versus the Equivalent Aerodynamic Diameter, EAD ($D_{P,50}$)).

The data of Table 3 and Figures 1 to 5 show the following features of interest:

1. The AMAD was significantly larger than the MMAD corresponding to the carrier dust (Table 3 and Figure 2), an experimental finding in full agreement with previous work (5).
2. On average, the AMAD and MMAD at the crusher platform were larger than the corresponding values at the mechanic's work bench. This was true before the installation of the wet scrubber and during the operation of the scrubber (see Table 3 and Figure 1). This mainly reflects the effect of crushing operations in the neighbourhood of the crusher.
3. The AMAD was reduced drastically during the operation of the wet scrubber: from 5.3 μm to 2.75 μm at the crusher platform, and from 4.9 μm to 2.59 μm

at the mechanic's work bench. Similarly, the MMAD was also correspondingly reduced from 4.4 μm to 1.6 μm, and from 2.4 μm to 1.1 μm for the crusher platform and the mechanic's work bench, respectively (see Table 3 and Figures 2 and 3).

4. The AMAD at the wet scrubber itself was dramatically reduced from 2.5 μm at the intake to 0.44 μm at the exhaust (see Table 3 and Figure 4).
5. Only slight variations in the AMAD corresponding to the thoron progeny, AMAD(TnD), were observed. Table 3 and Figure 5 show that thoron progeny attach themselves preferentially to particulate matter in the submicron range, i.e., in the range 0.14 to 0.19 μm in the crusher area, e.g., crusher platform and the mechanic's work bench. Attachment of thoron and radon progeny to submicron particulates has been amply documented elsewhere (5). A modest decrease in AMAD(TnD) was noticed during the operation of the wet scrubber at the crusher platform (see Table 3 and Figure 5). An even smaller difference in AMAD(TnD) was observed at the mechanic's work bench. It should be noted that some difference in AMAD(TnD) was also observed between the crusher platform and the mechanic's work bench prior to installation and operation of the wet scrubber. The differences in AMAD indicated above are to be expected because of location and air flow condition differences between the crusher platform and the mechanic's work bench.

Figures 6 and 7 show percentage (%) of the total α-particle activity measured in cascade impactor samples versus impactor stage cut-off size. These Figures show data prior to, and during, the operation of the wet scrubber for the crusher platform (Figure 6), and for the mechanic's work bench (Figure 7). Figures 6 and 7 show the following features:

a) a maximum (peak) percentage α-particle activity at a given cut-off size;
b) a rapid increase in percentage α-particle activity from small particle

size ($\lesssim$0.2 μm) to the maximum percentage activity size;

c) a decrease in percentage α-particle activity from the maximum percentage activity to the coarser particle size range (up to $\gtrsim$13 μm).

In addition, Figures 6 and 7 show the following:

i) the maximum percentage α-activity measured during the operation of the wet scrubber (curves B) was lower, in percentage value, and displaced to lower cut-off size, as compared with data taken prior to the operation of the scrubber (curves A);

ii) the percentage α-activity data obtained during the operation of the scrubber were higher than those measured before the scrubber operation for values of particle cut-off size less than that corresponding, in each case, to the maximum percentage α-activity;

iii) the converse of item (ii) was true for particle cut-off sizes larger than that corresponding to the maximum percentage α-activity.

Furthermore, a comparison of Figures 6 and 7 show that for the crusher platform, as opposed to the mechanic's work bench:

1) the peaks, i.e., maxima, were more sharply defined;

2) percentage α-particle activity measurements were higher;

3) a much lower value for the particle cut-off size corresponding to the maximum percentage α-activity, i.e., 1.8 μm as compared with 3.3 μm (no scrubber). For the mechanic's work bench the particle cut-off sizes corresponding to the maximum percentage activity were not much different, i.e., ~3.0 μm (wet scrubber) and ~3.3 μm (no scrubber).

The discussion above can be summarized quite simply by stating that the wet scrubber was relatively inefficient in removing long-lived radioactive dust of size below approximately 1.8 μm, but quite efficient in removing long-lived radioactive dust of size above 2 to 3 μm.

Table 4 summarizes radon progeny and thoron progeny Working Level data,

i.e., WL(Rn) and WL(Tn), respectively. Data were taken at the mechanic's work bench before, and after, the installation and operation of the wet scrubber. The Table shows that WL(Rn) and WL(Tn) were reduced, respectively, by about 12% and 17% during the operation of the scrubber. The ratio WL(Tn)/WL(Rn) was also reduced, as a consequence, by approximately 5%.

Table 5 summarizes data previously discussed regarding the performance of the wet scrubber in reducing the concentration levels of long-lived radioactive dust, and other variables of interest, in the crusher area.

CONCLUSIONS

The wet scrubber substantially reduced the concentration of airborne long-lived radioactive dust in the crusher area, i.e., 68% at the crusher platform, and 39% at the mechanic's work bench. At the scrubber itself, the removal efficiency was about 88%.

The scrubber was quite efficient in removing long-lived radioactive dust of size greater than about 2 μm. However, the efficiency decreased very rapidly with decreasing particle size. Removal efficiency for submicron particulate matter was rather poor.

The AMAD corresponding to the long-lived radioactive dust was significantly reduced during the operation of the wet scrubber. Modest reduction in airborne radon progeny and thoron progeny Working Levels was brought about by the scrubber.

In summary, a significant reduction in dust concentration, long-lived radioactive dust concentration, MMAD, AMAD, and radon progeny and thoron progeny concentration was quite evident during the operation of the dust collector (scrubber). Because respirable dust and long-lived, as well as short-lived, airborne radionuclides may pose a potentially serious environmental and occupational hazard, the installation of the wet scrubber to

reduce dust emission has resulted in a much improved and desirable environmental condition from the health standpoint.

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Table 1 - Cut-off size of cascade impactor stages at a sampling flow rate of 13.1 L/min.

Impactor Stage	Cut-off Size µm
1	13.17
2	7.85
3	3.16
4	1.89
5	1.20
6	0.66
7	0.35
8	0.17

Table 2 - Effect of the wet scrubber on Long-Lived Radioactive Dust (LLRD) concentration at the crusher plant.

Wet Scrubber in Operation	Impactor Location	[LLRD]* mBq/m^3	Date
No	Crusher platform	126.3±25.1	June 16-20
No	Mechanic's work bench	34.9±17.8	" "
Yes	Crusher platform	40.3±14.4	Aug. 25-27
Yes	Mechanic's work bench	21.3±8.1	" "
Yes	Scrubber intake	226.0	Aug. 28-29
Yes	Scrubber exhaust	28.0	" "

* square brackets indicate activity concentration. The notation LLRD indicates long-lived radioactive dust.

Table 3 - Effect of the wet scrubber on Mass Median Aerodynamic Diameter (MMAD) and Activity Median Aerodynamic Diameter (AMAD) at the crusher plant. Data in the table represent average values.

Wet Scrubber in Operation	Impactor Location	MMAD μm	σ_g μg	AMAD(LLRD) μm	σ_g μm	AMAD(TnD) μm	σ_g μm
No	Crusher platform	4.40	2.90	5.30	2.84	0.19	3.00
No	Mechanic's work bench	2.40	5.40	4.90	3.18	0.15	2.87
Yes	Crusher platform	1.60	5.30	2.75	3.98	0.14	3.20
Yes	Mechanic's work bench	1.10	6.50	2.59	4.21	0.14	3.19
Yes	Scrubber intake	-	-	2.50	-2.00	0.17	3.08
Yes	Scrubber exhaust	-	-	0.44	3.01	0.17	2.82

Note: MMAD and AMAD stand, respectively, for mass median aerodynamic diameter and activity median aerodynamic diameter. The symbols TnD and σ_g stand, respectively, for thoron progeny and geometric standard deviation.

Table 4 - Effect of the wet scrubber on short-lived radioactivity concentration (radon progeny Working Level, WL(Rn), and thoron progeny Working Level WL(Tn)) at the crusher plant. Sampling was conducted at the mechanic's work bench.

Wet Scrubber in Operation	WL(Rn)	WL(Tn)	WL(Tn)/WL(Rn)
No	0.166±0.016	0.162±0.011	0.97
Yes	0.147±0.013	0.135±0.013	0.92

Note: The values given above for WL(Rn) and WL(Tn) represent average values calculated from measurements during the wet scrubber operation (August) and prior to the operation of the wet scrubber (June). WL(Rn) and WL(Tn) stand, respectively, for radon progeny Working Level and thoron progeny Working Level.

Table 5 - Percentage reduction for several variables of interest brought about by the operation of the wet scrubber.

Variable	% Reduction When Wet Scrubber On	Location
[LLRD]	68.1	Crusher platform
	39.0	Mechanic's work bench
	87.6	Crusher itself
MMAD	63.6	Crusher platform
	54.2	Mechanic's work bench
AMAD	48.1	Crusher platform
	47.1	Mechanic's work bench
WL(Rn)	11.4	Mechanic's work bench
WL(Tn)	16.7	Mechanic's work bench

Note: [LLRD], MMAD, AMAD, WL(Rn) and WL(Tn) stand, respectively, for long-lived radioactive dust concentration, mass median aerodynamic diameter, activity median aerodynamic diameter, radon progeny Working Level, and thoron progeny Working Level.

LIST OF ILLUSTRATIONS

Figure 1 - Percentage cumulative α-particle activity (LLRD) versus EAD($D_{P,50}$) during operation of the wet scrubber for the crusher, AMAD(EMR), and the mechanic's work bench, AMAD(C).

Figure 2 - Percentage cumulative α-particle activity (LLRD) versus EAD($D_{P,50}$) at the mechanic's work bench before the operation of the wet scrubber, AMAD(C), and during operation of the wet scrubber at the mechanic's work bench and crusher, AMAD(EMR+C). Also shown is the percentage cumulative mass versus EAD ($D_{P,50}$) at the mechanic's work bench before the operation of the wet scrubber, MMAD(C).

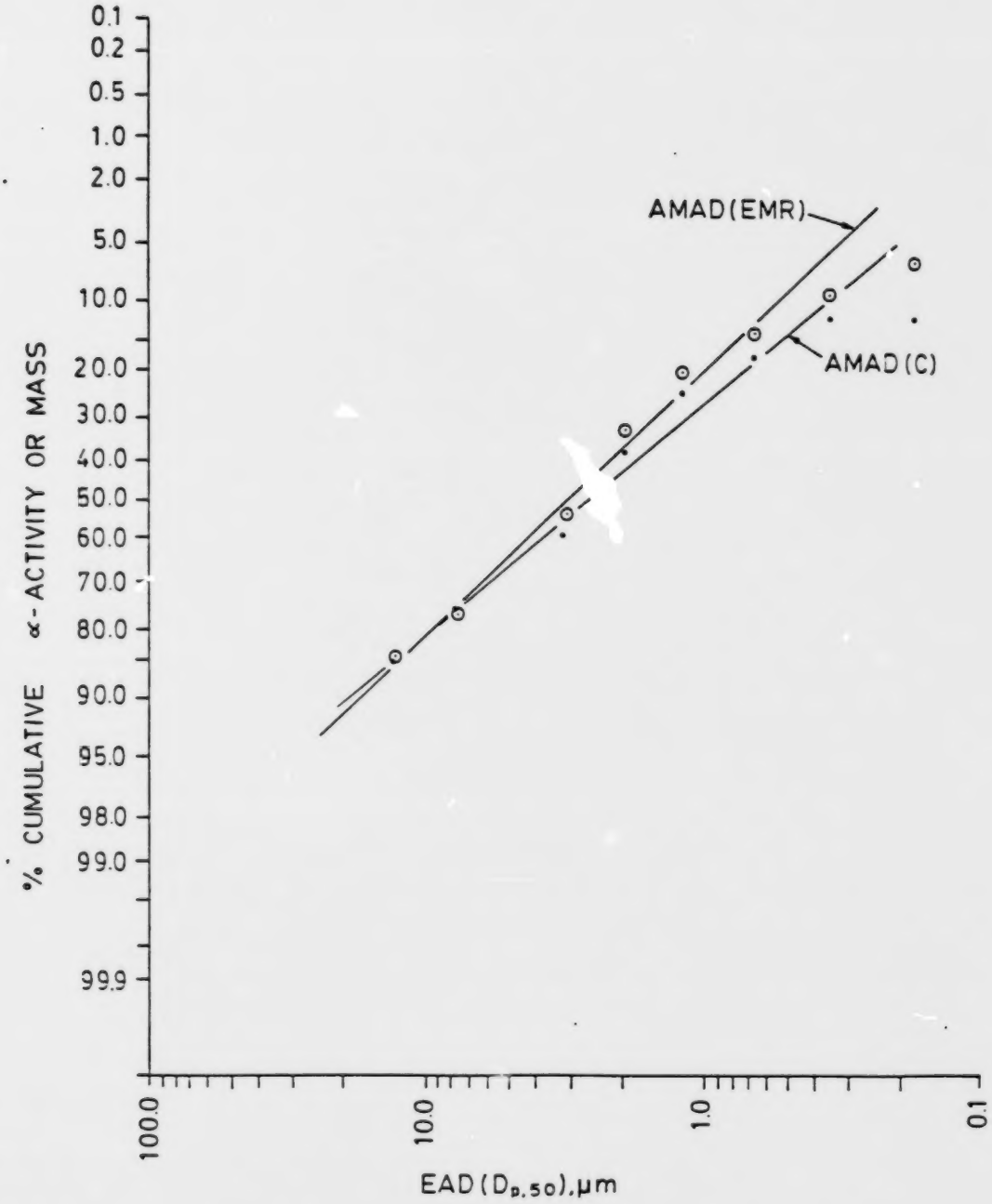
Figure 3 - Percentage cumulative α-particle activity (LLRD) versus EAD($D_{P,50}$) for the crusher before operation of the wet scrubber, upper AMAD(EMR) line, and during operation of the wet scrubber, lower AMAD(EMR) line. Also shown is the cumulative α-particle activity for the mechanic's work bench during operation of the scrubber, AMAD(C).

Figure 4 - Percentage cumulative α-particle activity (LLRD) versus EAD($D_{P,50}$) at the scrubber intake, AMAD(C), and the scrubber exhaust, AMAD(EMR).

Figure 5 - Percentage cumulative α-particle activity (thoron progeny) versus EAD($D_{P,50}$) at the crusher, AMAD(EMR), and at the mechanic's work bench, AMAD(C), before the operation of the wet scrubber. Also shown is the α-particle activity at the crusher and mechanic's work bench during operation of the wet scrubber, AMAD(EMR+C).

Figure 6 - Percentage α-particle activity (LLRD) versus impactor stage cut-off size measured at the crusher before (A) and during (B) operation of the wet scrubber.

Figure 7 - Percentage α-particle activity (LLRD) versus impactor stage cut-off measured at the mechanic's work bench before (A) and during (B) operation of the wet scrubber.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80.0
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99.9
% CUMULATIVE α-ACTIVITY OR MASS
AMAD(EMR)
AMAD(C)
100.0
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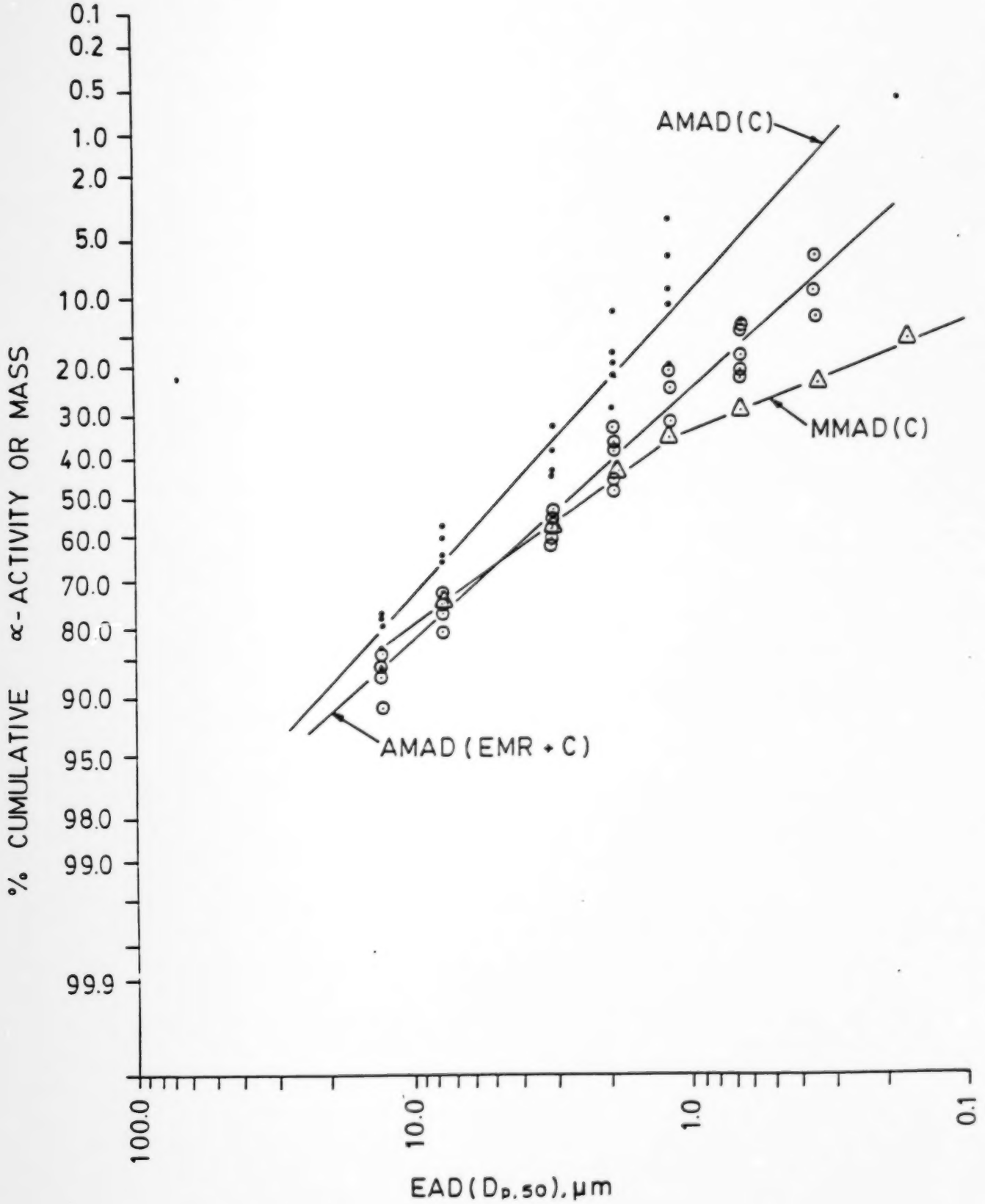
EAD ($D_{p,50}$), μm

Figure 1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60.0
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80.0
90.0
95.0
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99.9
AMAD(C)
MMAD(C)
AMAD(EMR+C)
100.0
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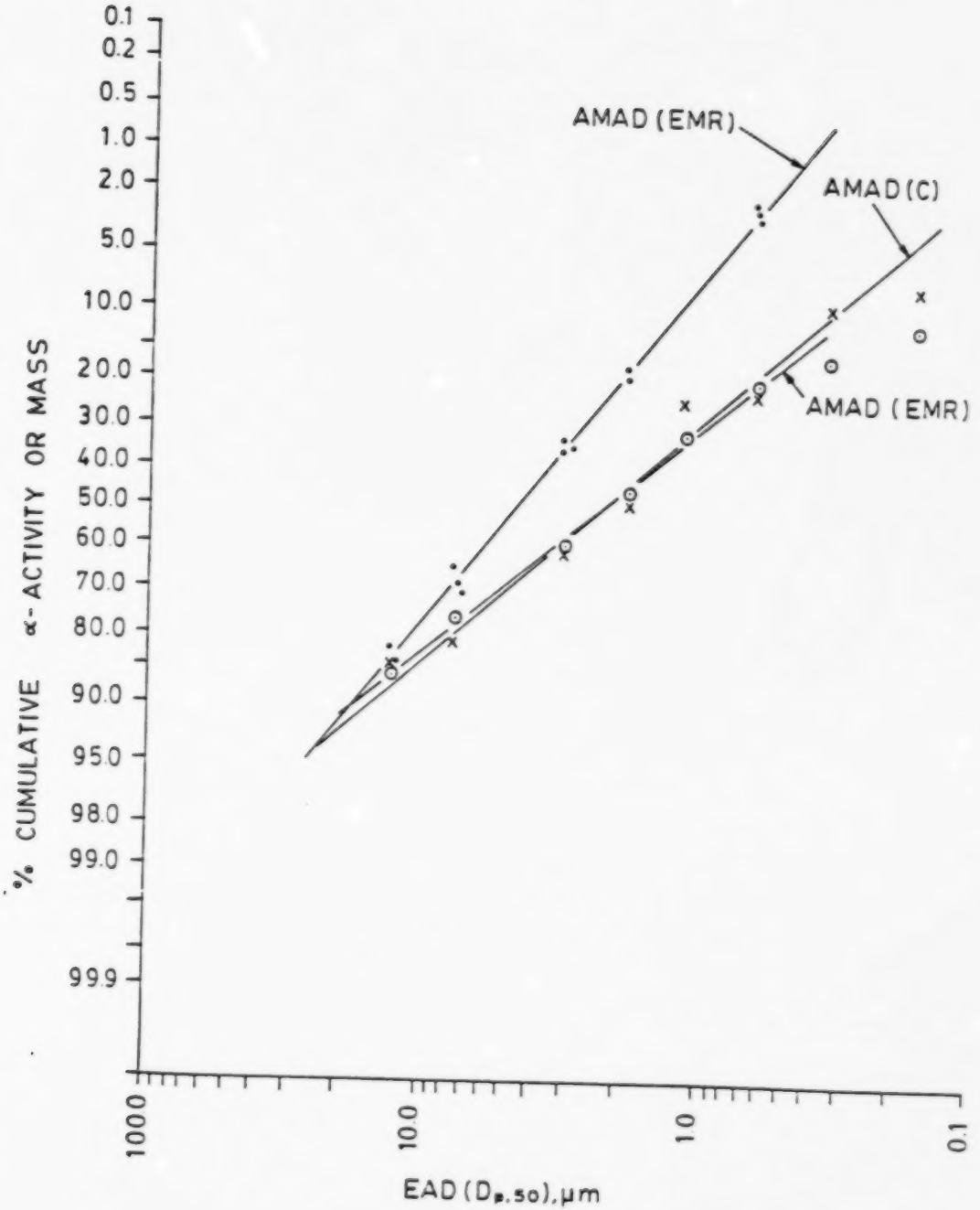
EAD(Dp,50), μm

Figure 2


AMAD (EMR)
AMAD (C)
AMAD (EMR)
% CUMULATIVE α-ACTIVITY OR MASS
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50.0
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70.0
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95.0
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99.9
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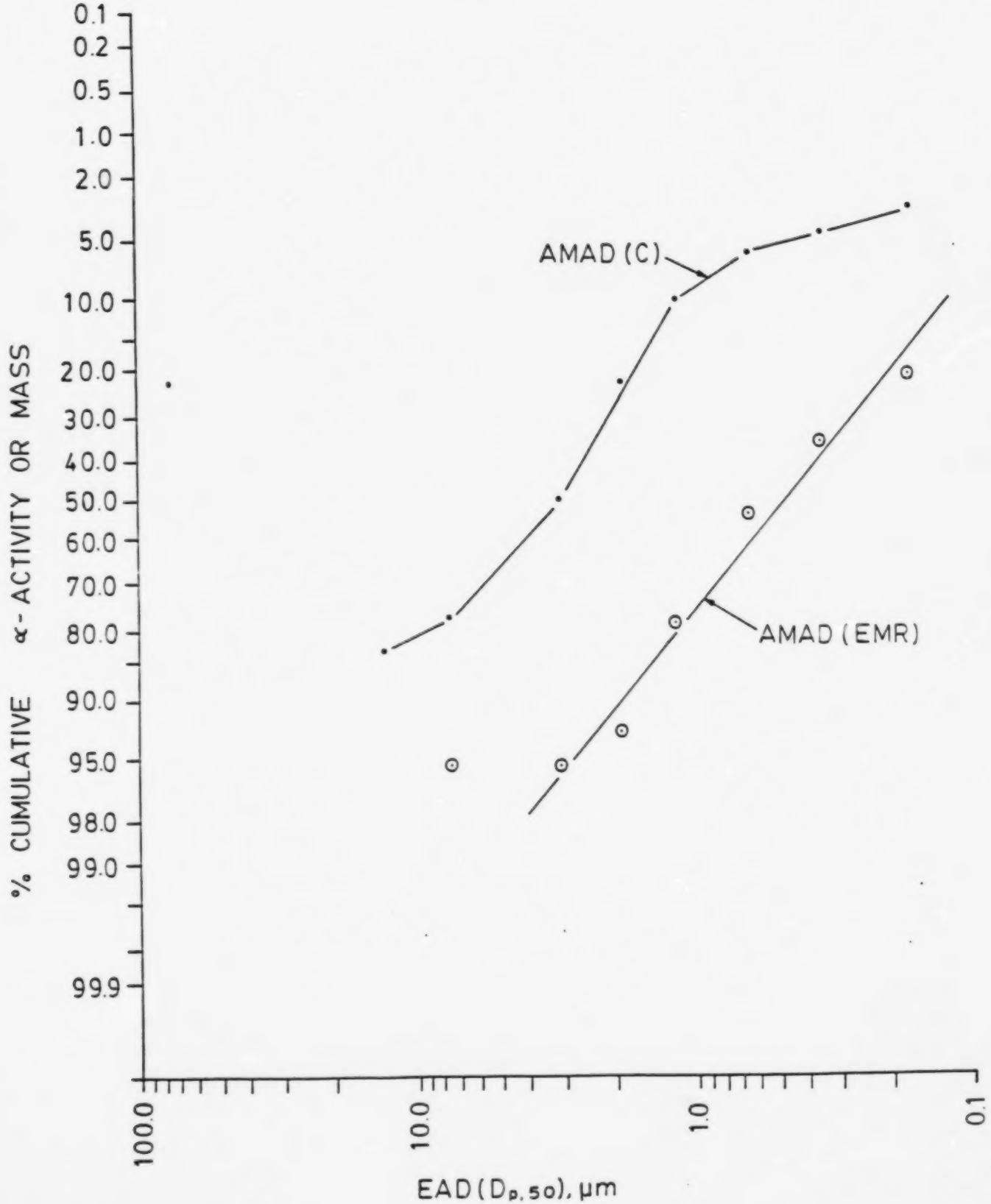
EAD (Dp.so), μm

Figure 3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99.9
% CUMULATIVE α-ACTIVITY OR MASS
AMAD (C)
AMAD (EMR)
100.0
10.0
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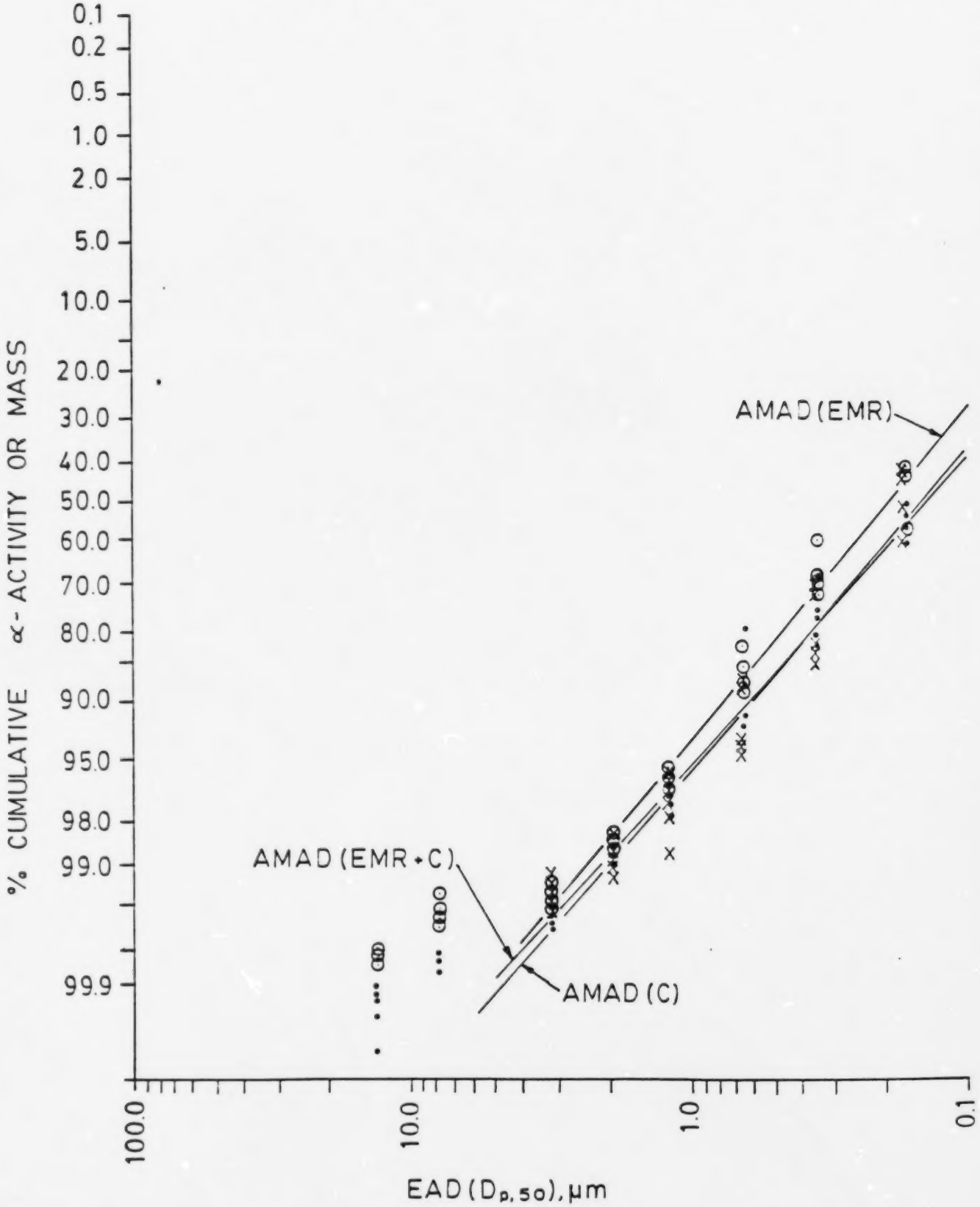
0.1
EAD (Dp, 50), μm

Figure 4


% CUMULATIVE α-ACTIVITY OR MASS
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40.0
50.0
60.0
70.0
80.0
90.0
95.0
98.0
99.0
99.9
AMAD (EMR)
AMAD (EMR+C)
AMAD (C)
100.0
10.0
1.0
0.1
EAD (Dp,so), µm

Figure 5

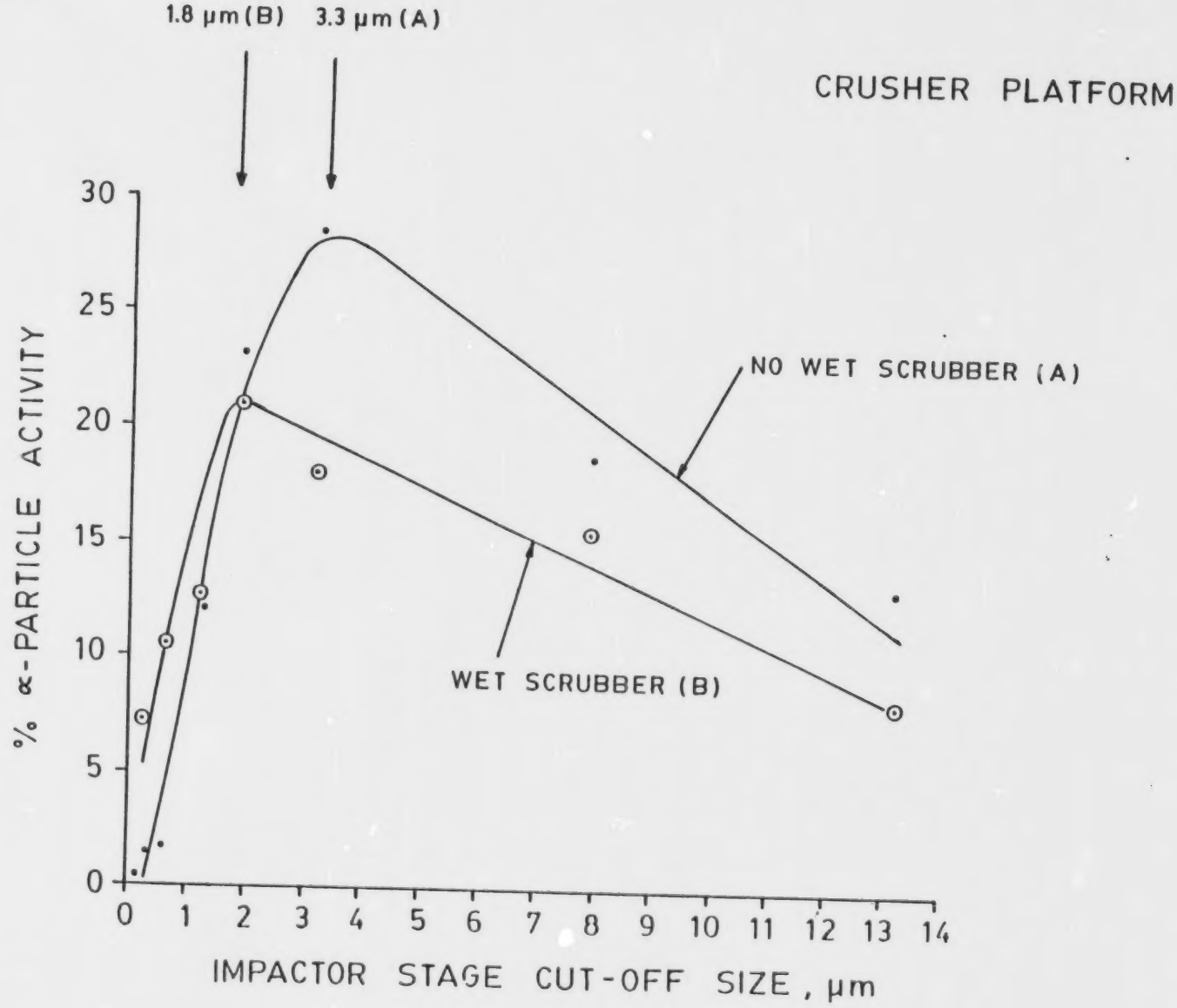
1.8 µm (B)
3.3 µm (A)
CRUSHER PLATFORM
NO WET SCRUBBER (A)
WET SCRUBBER (B)
% α-PARTICLE ACTIVITY
IMPACTOR STAGE CUT-OFF SIZE, µm
0
5
10
15
20
25
30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Figure 6

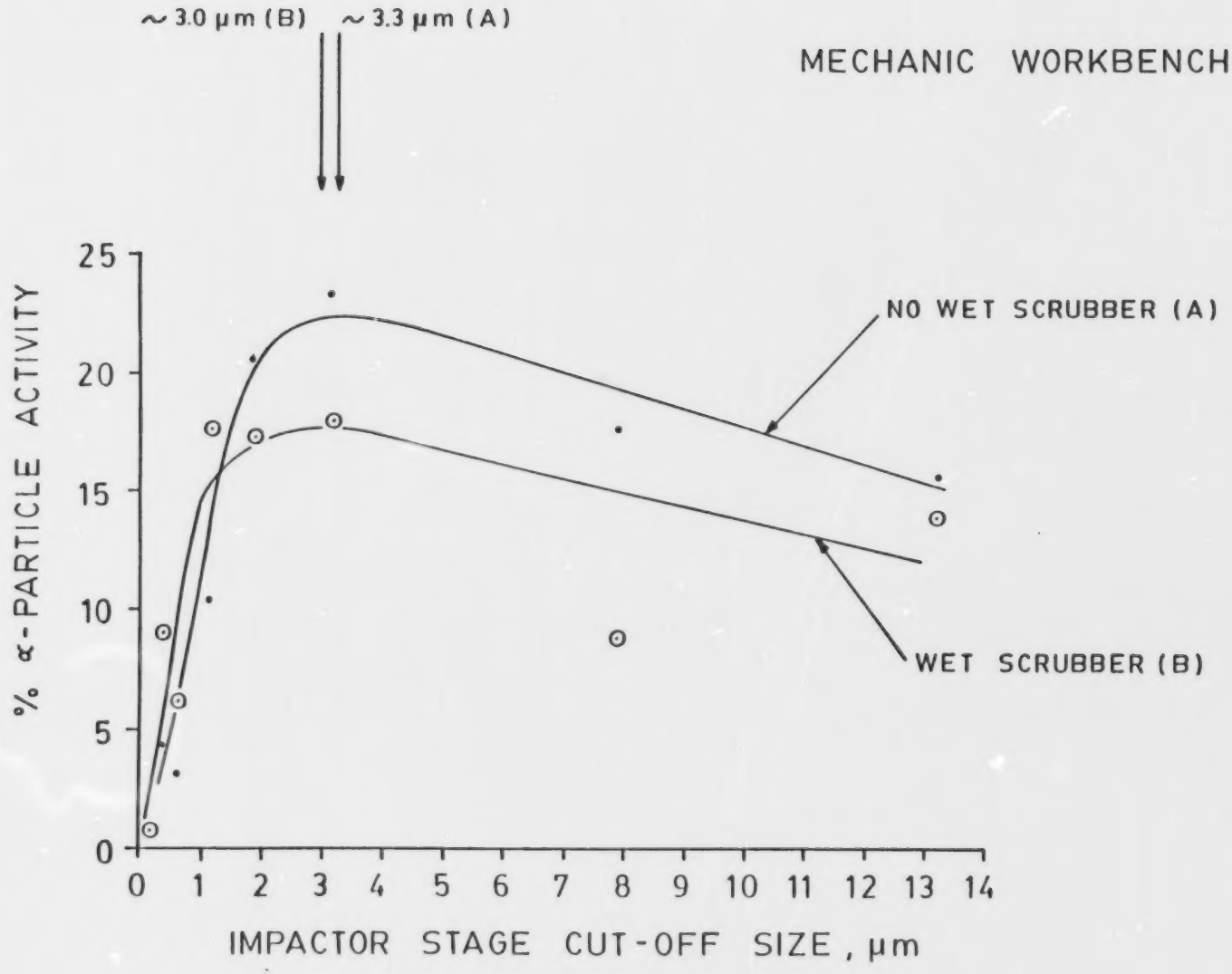
~3.0 µm (B)
~3.3 µm (A)
MECHANIC WORKBENCH
NO WET SCRUBBER (A)
WET SCRUBBER (B)
% α-PARTICLE ACTIVITY
0
5
10
15
20
25
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
IMPACTOR STAGE CUT-OFF SIZE, µm

Figure 7